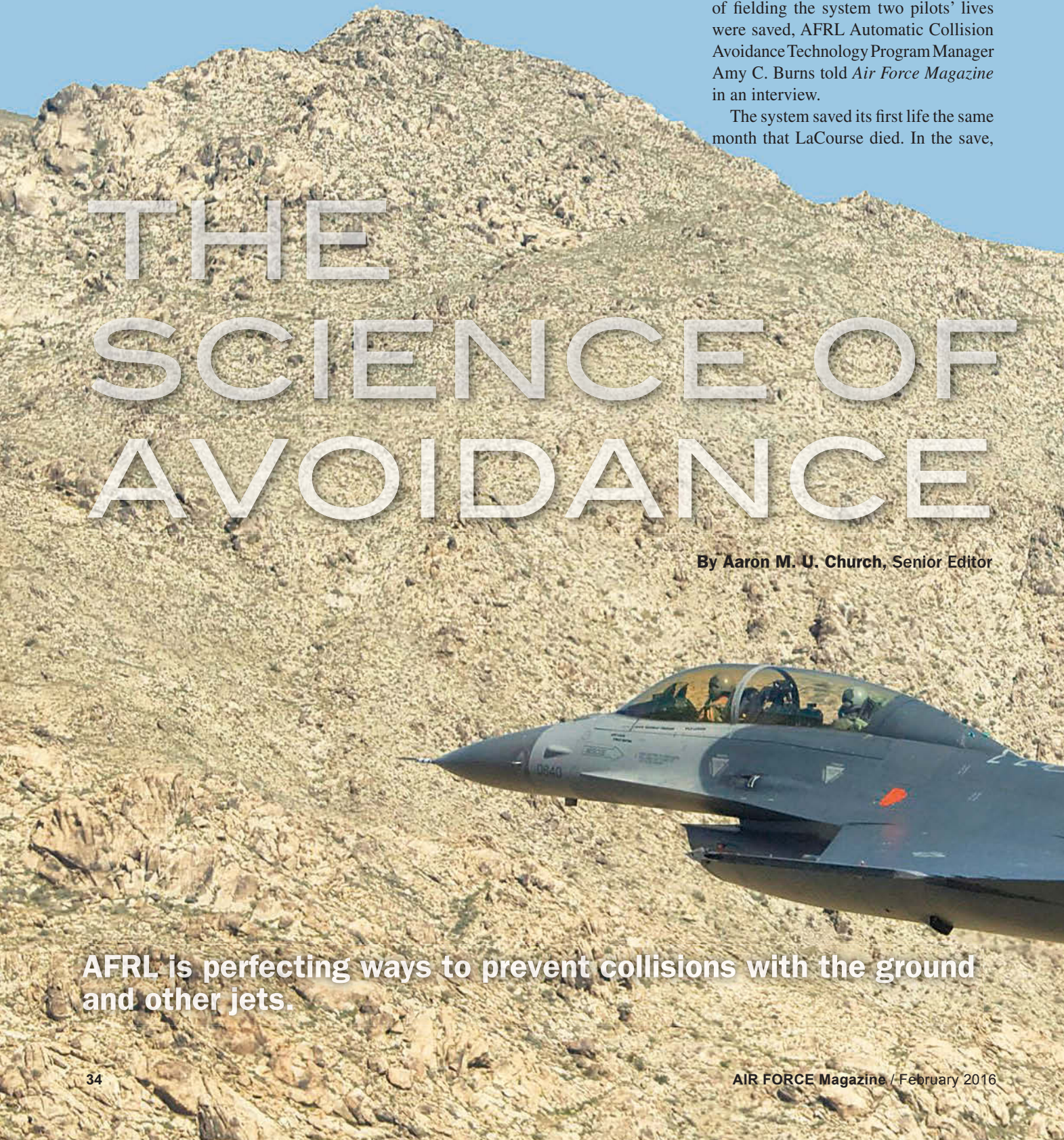
THE SCIENCE OF AVOIDANCE

By Aaron M. U. Church, Senior Editor



AFRL is perfecting ways to prevent collisions with the ground and other jets.

FLYING headlong into the ground is the single biggest killer of fighter pilots in the Air Force. The phenomenon known as Controlled Flight Into Terrain (CFIT) is responsible for 75 percent of F-16 pilot fatalities and is often due to disorientation or loss of consciousness while maneuvering at low altitude.

Separate CFIT incidents killed two F-16 pilots during the last two months of 2014 alone. Contract pilot and retired Lt. Col. Matthew LaCourse crashed into the Gulf of Mexico after becoming disoriented during an intercept mission out of Tyndall AFB, Fla., on Nov. 6, 2014. A month later, Capt. William H. Dubois hit the ground after losing his bearings on landing approach at a base in the Middle East during Operation Inherent Resolve, Dec. 1, 2014.

At the time, the Air Force had just begun implementing the cure for this deadly scourge.

In September 2014, the F-16 program office began retrofitting the F-16 Block 40/50 fleets with a revolutionary new Automatic Ground Collision Avoidance System (Auto-GCAS), developed by the Air Force Research Laboratory at Wright-Patterson AFB, Ohio. Within four months of fielding the system two pilots' lives were saved, AFRL Automatic Collision Avoidance Technology Program Manager Amy C. Burns told *Air Force Magazine* in an interview.

The system saved its first life the same month that LaCourse died. In the save,

AFRL's new collision avoidance system automatically pulled a pilot out of a high-angle strafing attack split seconds before the aircraft struck the ground. "The system kicked on at the very last possible second and recovered the aircraft" just over 500 feet above the earth, said Burns.

The system saved a second pilot's life during a training sortie over the Mediterranean less than two months later. The second pilot, deployed with the 480th Fighter Squadron from Spangdahlem AB, Germany, wrote a letter to the AFRL team, thanking them for saving his life. "Auto-GCAS worked as advertised and allowed me the honor to write this," he penned.

The unnamed pilot added the somber note that he "personally knew the pilots who died in the two most recent F-16 mishaps, both of which may have been preventable if we had Auto-GCAS implemented earlier."

CFITS AND STARTS

Engineers have tried to prevent F-16 pilots from flying into the ground since the aircraft was first fielded. Before Auto-GCAS "there were actually six different manual warning systems that were put on the F-16 to try to protect pilots," admitted Burns. The downfall of each was a warning to pilots who were incapacitated or incapable of recovering the aircraft could not save lives. Worse yet, systems often annoyed pilots by warning them too early, causing them to ignore or even switch the safety systems off.

"If you go back and look at the accident rate per flight hour, it hadn't changed even though all these systems had been added," Burns pointed out. Her team quickly determined that a successful system would need to be "nuisance free" and capable of taking control and recovering the aircraft automatically if needed.

Research into automatic recovery systems stretched back to the 1980s, but it wasn't until early 2007 that serious efforts got underway to develop an operational system. The joint program, initially led by NASA's Dryden Flight Research Center, was stoked by a Pentagon directive to identify and prevent the leading causes of accidents.

"The goal was to reduce them by up to 75 percent, and when they looked at the top reasons for aviation mishaps, controlled flight into terrain and midair collisions were the top two reasons," explained Burns.

AFRL decided to tackle the problem in three phases, starting with ground avoidance, moving on to midair collisions, and finally merging the two into a single system for the F-16 and eventually the F-35.

Fighters are far more susceptible to these types of accidents than larger, slower aircraft that rarely maneuver aggressively at low altitute. Unlike the F-15, the three fly-by-wire aircraft are already essentially controlled by computer. AFRL focused on aircraft where they could "add software to the flight control computer and parts of the avionics to make the system work," noted Burns, though similar systems could theoretically be developed for non-fly-by-wire aircraft as well. Since the F-16 fleet meets the above criteria

NASA photo by Jim Ross

An F-16D with automatic collision avoidance technology flies close to a hill in the Mojave Desert in 2009. The Air Force Research Laboratory's collision avoidance technology began on the F-16.

and makes up a sizable portion of the Air Force's fighter inventory, work began on the Viper.

Cooperating with NASA, AFRL completed 103 operational test flights on the Automatic Collision Avoidance Technology (ACAT) program's F-16D test bed, before handing its work off to the three fighter program offices for integration in 2010.

The F-16 program office fielded the first full Auto-GCAS on late block aircraft last September, and AFRL is still working on a solution for earlier F-16s, largely flown by the Air National Guard and Air Force Reserve Command.

The F-22 program office chose to adopt a different system, but tailored it to the Raptor's individual needs.

Plans call for fielding an Auto-GCAS on the F-35 sometime around 2024.

GROUND AVOIDANCE

AFRL took a novel approach in developing Auto-GCAS. Unlike previous systems, it is based on calculated time-to-impact, rather than altitude. At high speeds and steep dive angles, initiating a recovery at a predetermined altitude may not prevent a fighter from hitting the ground.

Auto-GCAS constantly calculates the aircraft's time to potential impact and intervenes only at the last moment to prevent a crash. "We had pilots go out and fly many different maneuvers toward the ground, at all different dive and bank angles" in testing, said Burns. What the team discovered was that "pilots really don't want to get any closer to the ground than about 1.5 seconds" from impact, she said.

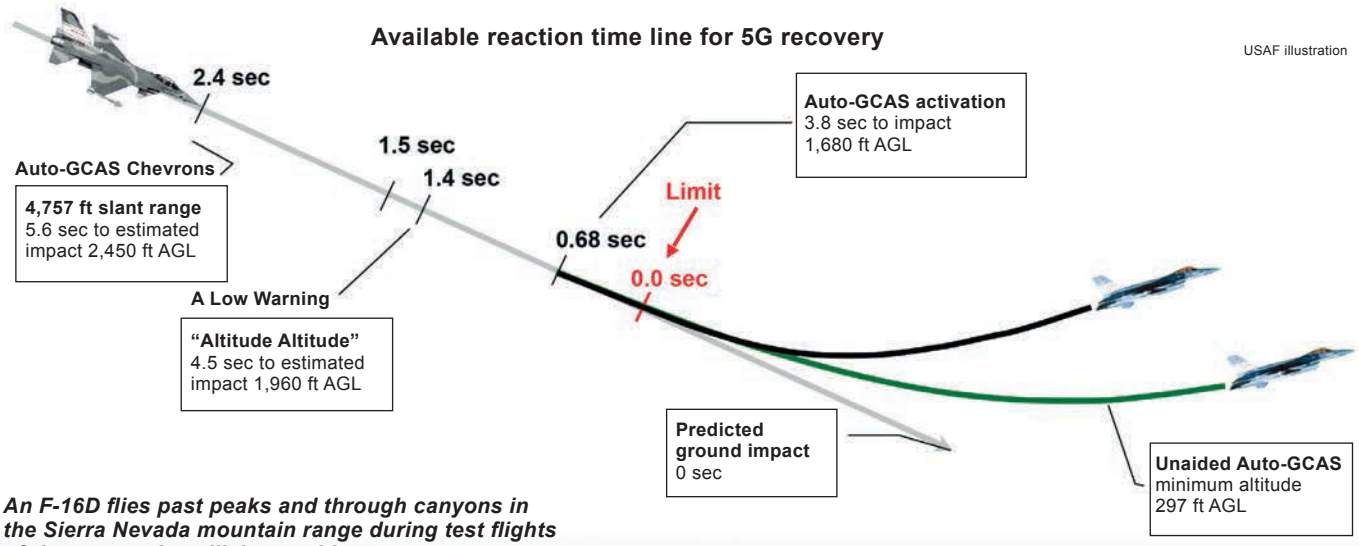
A computer taking control sooner than this inhibits the pilot's ability to fly the mission, so the team "designed it to activate between ... 0.25 and 0.8 seconds of available reaction time."

The time span is too short for the pilot to recover the aircraft unaided but sufficient to allow a computer to pluck the jet from disaster, roll the wings level, and execute a five-G pull up before releasing control back to the pilot.

If the pilot is conscious and pulls back on the stick to aid the recovery, the F-16 can actually exceed the automatic five-G pullout to recover quicker. The first pilot saved by the system

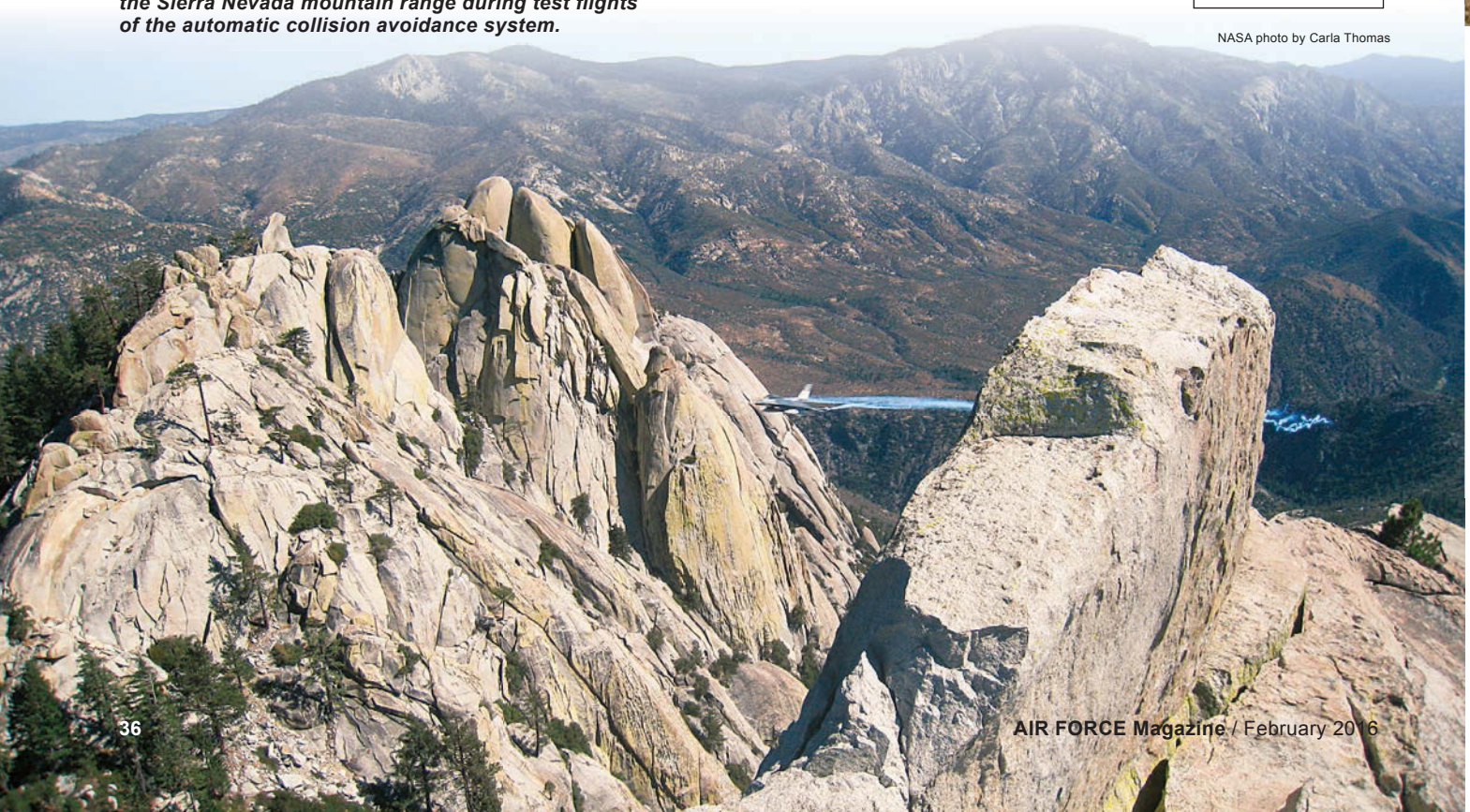
Available reaction time line for 5G recovery

USAF illustration



An F-16D flies past peaks and through canyons in the Sierra Nevada mountain range during test flights of the automatic collision avoidance system.

NASA photo by Carla Thomas




USAF photo

said Burns. Since the Air Force still operates a sizeable number of pre-Block 40 aircraft in the Guard and Reserve and for testing and training, the AFRL team is devising a separate solution.

The Hybrid Technology Program will physically add hardware to earlier aircraft to enable software mods. "We added digital processor cards to the analog flight control computer and a new mother board, so these digital processor cards give you the capability to add other automatic technologies," recounted Burns.

MOVING TARGETS

AFRL is flight-testing the hardware and software package at Edwards AFB, Calif., and working with the F-16 program and the ANG to integrate Auto-GCAS onto the remaining F-16s, though they're "still working on a timeline," she said.

While integrating the technology onto the F-22 is less convoluted, the program chose to adopt only parts of AFRL's software—keeping the auto-recovery maneuvers, but discarding the terrain-scanning feature in favor of a simple, preset altitude.


USAF photo

An F-16C (above) lost part of its wing in a midair collision during flight training near Moline, Kan., in 2014. The other F-16C (here) was a total loss. Both pilots survived.

assisted, and pulled seven Gs, recovering at 1,680 feet above the ground—roughly 1,300 feet higher than the system would have recovered him automatically.

Auto-GCAS projects a series of converging chevrons on the pilot's head-up display and produces an audible warning before taking over, and the pilot does still have the option of disabling the system if required. "The way the system works is that, prior to takeoff, the pilot loads digital terrain elevation data onboard the aircraft" giving the system a computerized topographical map of the airspace, explained Burns. GPS and inertial navigation data from the F-16 allows Auto-GCAS to pinpoint the aircraft's location and "scan" ahead of it to identify potential obstacles.

"It creates a two-dimensional profile of the highest points and at the same time it's constantly calculating recovery trajectory, and if it ever thinks the recovery trajectory's going to hit that, … it would go ahead and command the recovery," she said.

The system is "purely a software update" making it quicker and easier to transition to the operational fleet. Being a software upgrade also posed a problem for earlier model F-16s, however, because they employ analog—rather than digital—flight control computers. On the earlier F-16s, "there was no software to modify,"


NASA photo by Carla Thomas

The F-16D with ACAT testbed flies close to mountain peaks in the Sierra Nevada.

CFIT accounts for the lion's share of F-16 fatalities, but in terms of sheer number of accidents, midair collisions destroy almost as many aircraft. AFRL calculates that 24 percent of F-16 operational losses are due to hitting other aircraft. Two ANG F-16s collided during an air-to-air training exercise over

USAF photo by MSgt. John Nimmo

MSgt. Mark Caton (r) and SMSgt. Mark Jones swap out an air combat maneuvering instrumentation pod on an F-16 at Barksdale AFB, La. ACMI pods are often used during training missions to record data and, linked together, can trade avoidance signals.

Kansas in October 2014, mirroring a nearly identical incident off the coast of Virginia a year earlier. In each case pilots were injured, one F-16 was destroyed, and the second was severely damaged.

A third F-16 collided with a civilian Cessna during a training sortie last July, forcing the pilot to eject and killing the two civilian pilots.

Unlike terrain strikes, midair incidents disproportionately occur during training—particularly during maneuvering engagements. As a result, AFRL's Automatic Air Collision Avoidance System—phase two of the program—is tailored specifically to preventing training accidents.

Dodging a moving aircraft requires a greater variety of preprogrammed maneuvers and coordination between aircraft. During training flights, F-16s often carry an Air Combat Maneuvering Instrumentation (ACMI) pod to record flight data for debrief. Burns' team opted to use the pod to link aircraft together to continuously swap avoidance signals.

The system constantly calculates possible avoidance moves, communicates with the other aircraft, and "agrees upon a recovery," Burns said. Like the other system, Auto-ACAS only takes control and executes the avoidance maneuver at the last possible moment, to prevent interfering with the mission.

The Auto-GCAS' pull-up maneuver could cause a midair collision instead of preventing it, so Auto-ACAS has "nine different recovery maneuvers it can select from," said Burns. These include a "bunt" to push the nose below another aircraft, a "maintain" that automatically locks out the controls until danger is averted, and seven unique "roll-and-pull" maneuvers, she said.

With Auto-ACAS' move to Edwards to begin flight testing in January, the ACAT program's next challenge is bringing the two systems together. "We've now moved on to phase three, which is working on combining the air collision avoidance system with the ground collision avoidance system into an integrated collision avoidance system" (Auto-ICAS), Burns reported. Harmonizing both requires prioritizing potentially conflicting commands.

The team is working to modify Auto-ACAS "to make sure it's ground aware and doesn't pull you into the terrain"—and likewise, that Auto-GCAS doesn't pull a jet onto a collision course with another aircraft—along with several other upgrades. The team has already begun working on Auto-ICAS and plans to begin flying it on the F-16 at Edwards in April.

"AFRL's goal is to have our program completed at the end of the calendar year 2017," said Burns. "Then it will be each program office's responsibility to pick it up if they're interested and then do whatever testing is required" for integration onto the F-16, F-22, and F-35 fleets.

Beyond fighters, Burns' team is toying with research into adapting collision avoidance technology for heavier aircraft, such as airlifters, in conjunction with the Air Force Institute of Technology. "We've just done really basic research" looking at how the needs of heavier aircraft differ from fighters, she said.

In the case of a heavily loaded C-130 "you might not always want to pull them over the mountains." Given their slower speed "you might want to do more of a lateral escape maneuver" instead, she said. "We have efforts with AFIT that are underway to look at other recovery maneuvers, … but that is in the research phases still." ✪